DIFFUSION SEPARATION OF FLUIDS

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FIG. 1.

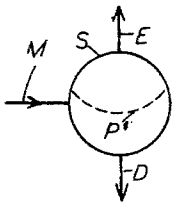



FIG. 5.

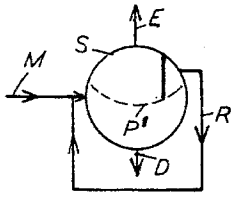
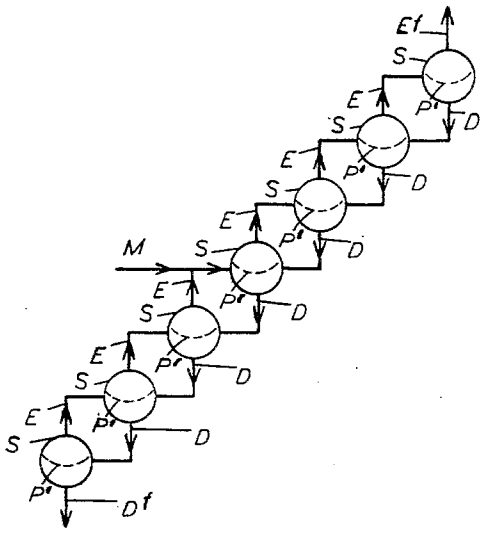



FIG. 2.




Inventors
K. Fuchs
By R. E. Peierls
F. E. Simon
Glenn R. Downing & Cuthbert
Attorneys.

DIFFUSION SEPARATION OF FLUIDS

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FIG. 3.

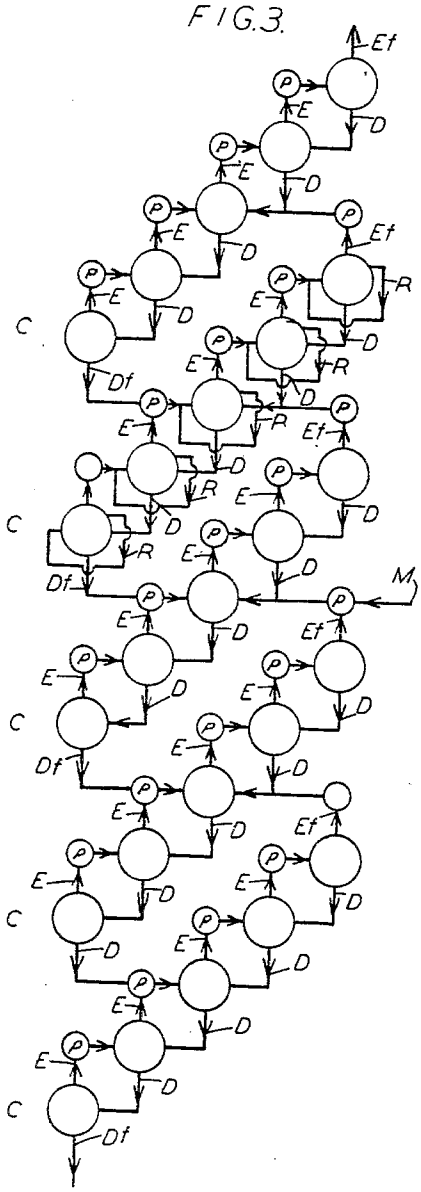
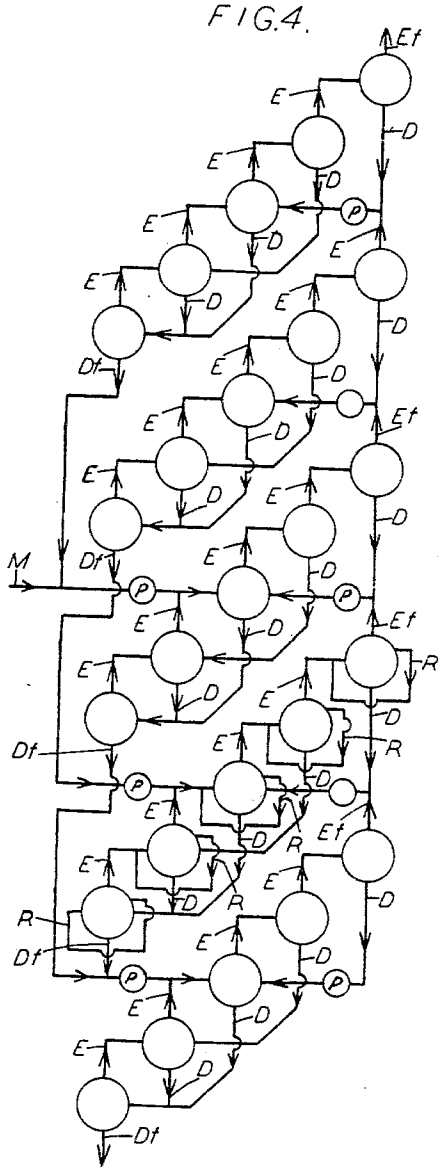



FIG. 4.




Inventors
K. Fuchs
By R. E. Peierls
F. E. Simon
Glascock Downing & Seebold
Attorneys

DIFFUSION SEPARATION OF FLUIDS

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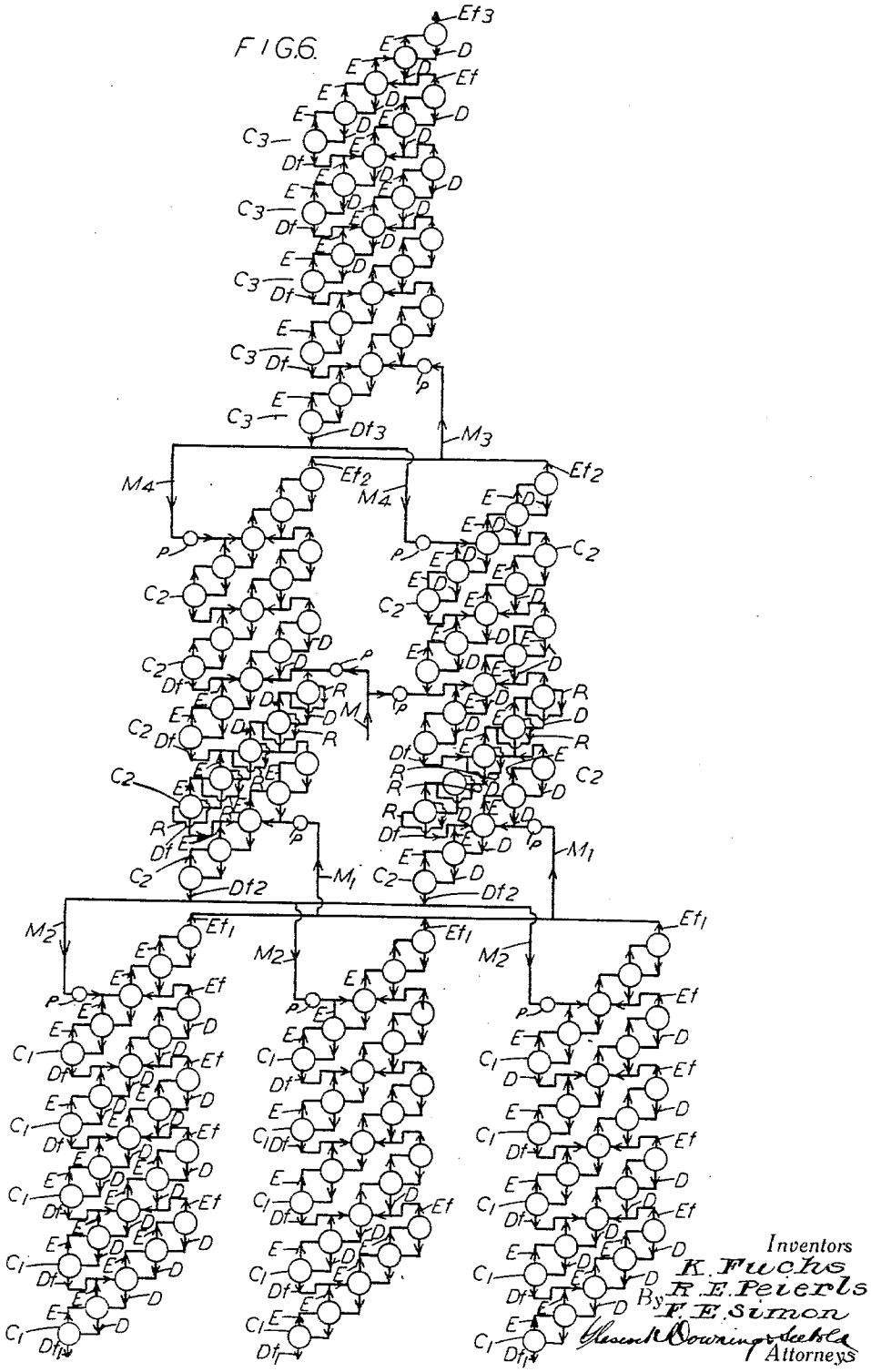


Inventors
K. Fuchs
R. E. Peierls
By F. E. Simon
Glasco & Downing & Seebold
Attorneys

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# 3,208,197
# DIFFUSION SEPARATION OF FLUIDS

Franz Eugen Simon, Oxford, England, and Klaus Fuchs and Rudolph Ernst Peierls, Santa Fe, N. Mex., assignors to the United States of America as represented by the United States Atomic Energy Commission

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17 Claims. (Cl. 55—16)

This invention relates to the diffusion separation of mixtures of gaseous or vaporous media by means of porous membranes.

In the accompanying drawings:

FIG. 1 is a conventional diagram illustrating apparatus for performing a single separating operation.

FIG. 2 is a diagram illustrating the interconnection of a number of pieces of the apparatus shown in FIG. 1, whereby a cascade effect is obtained.

FIG. 3 is a diagram illustrating a simple embodiment of the present invention.

FIG. 4 is a diagram illustrating a simple alternative embodiment of the invention.

FIG. 5 is a diagram illustrating a modification of FIG. 1, and

FIG. 6 is a diagram illustrating another simple embodiment of the invention.

As indicated in FIG. 1, the mixture to be treated is led, arrow M, into a separating device S, and as a result of the treatment two fractions, arrows E and D respectively, are led out. For example, if the component it is desired to collect is that which diffuses more rapidly through the membrane than the other component, i.e. the component which will for convenience be termed the lighter component because in general it will be the component of lower molecular weight, then as indicated in FIG. 1, the mixture is led to one side of a porous membrane P′. The fraction which diffuses through, arrow E, will have its concentration in the light component increased, while the fraction which does not diffuse through, arrow D, will have its concentration in the light component reduced, or in other words will have its concentration in what may be termed the heavy component increased. For convenience the former fraction will be termed the enriched fraction and the latter the depleted fraction.

It is emphasised that the terms "light," "heavy," "enriched" and "depleted" are used solely for convenience and that they are not intended to limit the invention, as will be understood by those skilled in the art.

The separating effect of a single treating operation taking place in the apparatus of FIG. 1, which may be termed a stage, may be quite small, i.e. the output fractions may differ very little in composition from the input mixture. It is known to use a cascade or succession of stages in series both ways, i.e. with connections for passing the enriched fraction forward to a succeeding stage and the depleted fraction back to a preceding stage, the mixture being supplied to the cascade at any suitable point. If the mixture is supplied at some point between the ends of such a cascade, for example midway, the stages forward of this point are usually termed the "rectifying" section and the stages preceding this point are usually termed the "stripping" section.

The enriched product is withdrawn at the last stage, forming the whole or part of the enriched fraction of that stage, whereas a corresponding amount of strongly depleted material is taken out at the opposite end where it forms the whole or part of the depleted fraction of the end stage of the stripping section.

A simple form of cascade is shown in FIG. 2 of which each stage is similar to FIG. 1. In this cascade the

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enriched fraction from each stage except the last, is led forward to the next succeeding stage, arrows E, and the depleted fraction from each stage except the first is led back to the next preceding stage, arrows D. The arrow E*f* indicates the final enriched output of the cascade and the arrow D*f* the final depleted output. The mixture is introduced at a suitable point having regard to its composition, the separating effect of the stages and the like factors and is shown in this example as entering at the mid-stage, arrow M.

Other, more elaborate, cascade arrangements are known, for example the enriched and depleted fraction are carried forward and back respectively to stages which are not those next succeeding or preceding. Also some stages may separate the input mixture into more than two fractions, in particular into three fractions one of which is led back for re-treatment in the stage from which it emanated.

As FIG. 2 is merely a diagrammatic illustration, only seven stages are shown, but in practice a cascade constituting a complete plant may need a far greater number, depending on the separating effect per stage and the final degree of separation reqiured, and the present invention is more particularly concerned with plants in which a high number of stages is necessary.

According to the present invention a cascade as above described is subdivided into a number of sub-cascades, the connections within each of which are as described above. Each subcascade, therefore, produces from the material fed into it an enriched and a depleted product, the degree of enrichment and of depletion being greater than those for a single stage but less than those for the entire plant.

The connections between the different sub-cascades are similar to those of stages in a plant, the enriched and depleted output from a subcascade being led forward and backward respectively to succeeding and proceding subcascades in a similar manner to the enriched and depleted fraction of a single stage in a single cascade.

A simple embodiment of the invention is shown in FIG. 3. Here there are five sub-cascades C the internal connections of which, indicated by the arrows ED, are identical to those of the cascade of FIG. 2, while the connections between the sub-cascades, indicated by the arrows E*f*, D*f* are identical to those within the sub-cascades. In this example, within each sub-cascade the fractions are respectively fed forward one stage and backward one stage while between the sub-cascades the fractions are also respectively fed forward from one subcascade to the succeeding one and backward from one sub-cascade to the preceding one. As will be explained below, these fractions passing from one cascade to another are substantially smaller than the fractions passing from stage to stage. The mixture is shown as being fed in at the mid-point of the whole assembly, arrow M.

It can be shown that in operating a cascade plant, in general the value obtained by multiplying the mass rate of flow of media between two sections of the plant by the difference in concentration between the two sections, should be constant or approximately so. Since the change in concentration from one end of a sub-cascade to the other is to a first approximation as many times the change between two adjacent stages as there are stages in the subcascade, it follows that the total mass rate of flow out of the sub-cascade (and therefore also the total inflow into the sub-cascade) should be a fraction in the same ratio of that taking place between adjacent stages within the sub-cascade. In consequence the mass rates of flow of material that have to pass from one sub-cascade to the succeeding and preceding ones are the same number of times as small as the mass rates of flow of material that, in a single sub-cascade, are passed from one stage to the suc-

ceeding and preceding stages. Thus in FIG. 3 with the small number of stages shown for convenience, the total flow rate into and out of a sub-cascade C (arrows E*f* and D*f*) should be approximately ⅕th of the total flow rate into and out of any one stage, while the total flow rate into and out of the whole plant (arrows M and the final arrows E*f* and D*f*) should be ⅕th of that between sub-cascades, or $\frac{1}{25}$th of that between stages. In a plant comprising a single cascade, the above rule can be applied only at the ends of the cascade and even if the whole cascade is physically divided into sections, the mass rate of flow between the sections must be equal to the flow from one stage to another, whereas in a plant according to the present invention, though the flow rate between adjacent stages within a sub-cascade will in general be the same as in the equivalent single cascade plant, the flow rate between sub-cascades is but a small fraction of the inter-stage flow rate.

This reduction in the amounts passing between sub-cascades constitutes an important advantage of the present invention. It becomes possible for example to work the plant in independent sections, each section consisting of one or more sub-cascades and the circulation of material between different sections being small. If it is desired to store part of the material passing between sections in order to have a reserve that will keep other sections going in the event of one breaking down or if it is desired to purify or otherwise treat the material that passes between sections, the size of the equipment necessary for storage or treatment will be substantially smaller than in the case of sections of a single-cascade plant.

In general the input to each sub-cascade will consist of the enriched output from the next previous sub-cascade and the depleted output from the next succeeding sub-cascade and they will be led in to a common stage. The invention is not so limited, however. In some cases it may be desirable to carry a quantity of material backwards or forwards to a preceding or succeeding sub-cascade which is not the next. Similarly it may be desirable to carry a fraction from one stage to a preceding or succeeding stage which is not the next.

FIG. 4 illustrates a lay-out embodying both these features. For the sake of simplicity only five sub-cascades each comprising only five stages, are shown, but it will be understood that in practice the numbers will be usually larger. Where the number of steps in either direction exceeds one, the number forward must be different from the number backward, otherwise the assembly falls into separate sub-cascades or cascades. In the example of FIG. 4, both within the sub-cascades and between the sub-cascades, the forward step is one and the backward step two. Thus in each sub-cascade, each arrow E leads from one stage to the next, and each arrow E*f* from one sub-cascade to the middle stage of the next sub-cascade, while each arrow D (except the lowest but one in each sub-cascade) leads from one stage to the next but one preceding and each arrow D*f* (except that from the lowest sub-cascade but one) leads to the middle stage of the next sub-cascade but one. The lowest but one arrow D in each sub-cascade leads to the input of the lowest stage, and the arrow D*f* from the lowest but one sub-cascade leads to the middle stage of the lowest sub-cascade. The main mixture supply is shown as entering the middle stage of the middle sub-cascade, arrow M.

In all the illustrated lay-outs the two fractions entering any sub-cascade are shown entering the same stage, by way of example the middle stage, but it may be desirable to lead the two fractions entering a sub-cascade to different points within this sub-cascade. This may in particular be desirable if these two fractions are not of substantially the same composition. By suitable choice of the connections it is always possible to avoid mixing of fractions of appreciably different composition.

It may be desirable for more than two fractions to be taken from any one or more of the stages and to lead the fractions to different stages. In particular it may be desirable to take a third fraction from any one or more stages and lead it back for retreatment in the same stage as that from which it emanated. This is indicated for a single stage in FIG. 5 in which a fraction which diffuses through one part of the membrane P is led back, arrow R, to the inlet side of the casing S. Similar arrows R are shown at various points in FIGS. 3, 4 and 6.



It may be necessary to vary the size of the stages, that is to say the bulk rate of throughput which they can deal, at different points in the plant, depending on the proportions of the ingredients in the mixture and the degree of separation reached at the various points. To enable a single size of stage, or a small range of sizes, to be used in the interests of standardization, the required capacity at any point in the cascade or cascades may be provided by using in parallel a number of stages or complete sub-cascades of the selected size or sizes.

This is illustrated in FIG. 6 which by way of example relates to a plant for treatment of a mixture that contains a small proportion of the light component so that the final enriched fraction is smaller in quantity than the final depleted fraction. In the illustration, the lower end comprises three sets of five sub-cascades $C_1$ in parallel, from which the final depleted fraction is discharged, arrows $Df_1$, while the enriched fraction from this section is led, arrows $Ef_1$ and $M_1$, to the next section which comprises two sets of five sub-cascades $C_2$ in parallel. From this section the depleted fraction is led back to the first section, arrows $Df_2$ and $M_2$ while the enriched fraction is led, arrows $Ef_2$ and $M_3$ to the top section which comprises one set of five sub-cascades $C_3$. The depleted fraction from the final section is led back, arrows $Df_3$ and $M_4$, to the second section, while the enriched fraction, arrow $Ef_3$, from the final section constitutes the highest concentration of light component obtainable from the plant. The mixture to be treated will be led into the plant at a point or points appropriate to its composition, for example as shown by arrow M, at the mid-point of the second section. It will be understood that the number of sections, the number of sub-cascades in each set, the number of sets in parallel and so forth will be determined in practice according to the media in question and the conditions of operation.

Means such as compressors or pumps will be provided, as necessary, to propel the fractions and these may be located between the stages or between the sub-cascades as may be convenient. Such means are indicated at P in FIGS. 3, 4 and 6.

We claim:

**1.** A process for the treatment of mixtures of fluids by means which separates the mixture into two fractions of different composition by diffusion through a porous membrane, in which a cascade of distinct stages operating in series is subdivided into a number of sub-cascades within each of which one fraction from each stage except the last is passed forward to a succeeding stage and one fraction from each stage except the first is passed backward to a preceding stage, while the corresponding but substantially smaller fractions from the last and first stages of a sub-cascade are respectively led forward to a stage between the end stages of a succeeding sub-cascade and back to a stage between the end stages of a preceding sub-cascade, except in the case of the first and last sub-cascades, the corresponding fractions from which constitute the final output fractions of the plant.

**2.** A process according to claim **1** in which each sub-cascade, except the first and last, has the two fractions reaching it from succeeding and preceding sub-cascades led in to a common stage between its end stages.

**3.** A process according to claim **1** in which the two fractions leaving any stage, except the first and last of a sub-cascade, are led respectively to the next succeeding and next preceding stages.

4. A process according to claim 1 in which the corresponding fractions from the last and first stages of all except the last and first sub-cascades are led respectively to the next succeeding and next preceding sub-cascades.

5. A process according to claim 1 in which in at least one stage, more than two fractions are separated and each led to a different stage.

6. A process according to claim 1 in which in at least one stage, three fractions are separated, one of which is led back for retreatment in the stage from which it emanated.

7. A multi-stage process for the treatment of mixtures of fluids by means which separates the mixture into two fractions of different composition by diffusion through a porous membrane which comprises simultaneously effecting a plurality of distinct stages of separation which constitute a plurality of sub-cascades each comprising a plurality of stages, leading one fraction from each stage except the last within a sub-cascade forward to another stage within the same sub-cascade, leading one fraction from each stage except the first within a sub-cascade backward to another stage within the same sub-cascade, leading a corresponding but smaller fraction from the last stage of each sub-cascade except the last forward to a stage between the end stages of a succeeding sub-cascade, and leading a corresponding but smaller fraction from the first stage of each sub-cascade except the first backward to a stage between the end stages of a preceding sub-cascade.

8. Apparatus for the separation of mixtures of fluids into two fractions of different composition comprising a plurality of sub-cascades each including a plurality of porous membranes each adapted to effect a partial separation, a main inlet conduit leading to one of said membranes, a conduit leading forward from the outlet side of each said membrane except the last in each sub-cascade to the inlet side of a succeeding membrane within the same sub-cascade, a conduit leading backward from the outlet side of each said membrane except the first in each sub-cascade to the inlet side of a preceding membrane within the same sub-cascade, a conduit leading forward from the outlet side of the last membrane of each sub-cascade except the last to the inlet side of a membrane located between the first and last membranes of a succeeding sub-cascade, and a conduit leading backward from the outlet side of the first element of each sub-cascade except the first to the inlet side of an element located between the first and last membranes of a preceding sub-cascade.

9. Apparatus as set forth in claim 8 in which the forward leading conduits within each sub-cascade led from one membrane to the next.



10. Apparatus as set forth in claim 8 in which the backward leading conduits within each sub-cascade lead from one membrane to the next.

11. Apparatus as set forth in claim 8 in which the pitch of the forward leading conduits within a sub-cascade differs from the pitch of the backward leading conduits within the same sub-cascade.

12. Apparatus as set forth in claim 8 in which the two conduits leading to a sub-cascade from the succeeding and preceding sub-cascade respectively, lead in to a common point.

13. Apparatus as set forth in claim 8 in which the forward leading conduit from one sub-cascade leads to the next succeeding sub-cascade.

14. Apparatus as set forth in claim 8 in which the backward leading conduit from one sub-cascade leads to the next preceding sub-cascade.

15. Apparatus as set forth in claim 8 in which the pitch of the conduits leading forward from a sub-cascade to a succeeding sub-cascade differs from the pitch of the conduits leading backward from a sub-cascade to a preceding sub-cascade.

16. Apparatus as set forth in claim 8 also including means for leading out an additional fraction from the outlet side of at least one of the membranes and returning such fraction to the inlet side of the same membrane.

17. Apparatus as set forth in claim 8 also including at least one reservoir and means for diverting into the reservoir fractions normally supplied to a sub-cascade thereby enabling the sub-cascade to be taken out of action temporarily without cessation of operation of the remainder of the apparatus being necessary.


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REUBEN FRIEDMAN, *Primary Examiner.*

JAMES L. BREWINK, JOHN R. SPECK, KARL LESH, *Examiners.*